



TechData Sheet

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Energy Efficient Motors

This TechData Sheet is intended to help activity personnel identify cost effective energy projects for energy efficient motors. With this guide an energy manager can identify when an energy efficient induction motor should be used.

- Constant Speed
- Adjustable Speed
- Multi Speed
- Varying Speed
- Adjustable Varying Speed

MOTOR TYPES AND EFFICIENCIES

Motor Types

There is a wide variety of motor types. One way to categorize them is by their electrical source. DC, single phase AC, or three phase AC electrical supplies are the most common. Examples of each are:

DC	Shunt wound Series wound Compound wound
AC - 1 Phase	Repulsion Induction Repulsion-induction Series
AC - 3 Phase	Induction (Asynchronous) Synchronous

Another way to categorize motors is by their application or load. Loads can be classified into solids, liquids, and gasses (e.g., elevator systems, water pumps, and HVAC fan systems, respectively) and define such specifications as horsepower, speed, and torque design characteristics. Speed classifications are:

The load connection configuration defines specifications such as vertical or horizontal shaft position, pulley or direct drive, and speed. The environment defines motor specifications through ambient conditions and human factors. Ambient conditions such as humidity and ventilation define the needed enclosure type and cooling methodology. Human factors such as accidents, failures, or errors define specifications such as splash proof protection. Common open or totally enclosed enclosures are:

Open	Totally Enclosed
Drip proof Splash proof Guarded Semi-guarded Drip proof guarded Externally ventilated Pipe ventilated Weather protected, types I and II Encapsulated windings Sealed windings	Non-ventilated Fan cooled Fan cooled guarded Explosion proof Dust ignition proof Pipe ventilated Water cooled Water air cooled Air-to-air cooled

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Motor Efficiencies

The standards for energy efficient motors apply only to induction motors. This data sheet addresses only induction motor applications which are the most common. Motor efficiency is defined, in its simplest terms, as delivered shaft power divided by electrical input power. Not all of the electrical input is converted to mechanical power. The associated losses determine the efficiency of a motor. Motor losses are attributable to load independent and or load dependent causes. Typical losses and their usual range as a percent of total loss are given below:

Category	Loss (%)	Contributing Factors
Core (Iron)	15-25	Type and design of core material
Friction/Windage	5-15	Bearings and fan
Stator I ² R	25-40	Stator conductor impedance
Rotor I ² R	15-25	Rotor conductor impedance
Stray Load	10-20	Manufacturing and design

Motor Loss Categories

The National Electrical Manufacturers Association (NEMA) established standards for motor efficiency. Following NEMA standard for induction motors, efficient motor designers and manufacturers have improved overall motor performance with respect to nominal efficiency and power factor. Nominal motor efficiencies are defined by the American National Standards Institute (ANSI) testing standards C50.20.

WHEN TO BUY ENERGY EFFICIENT MOTORS

Energy efficient motors should be considered in the following circumstances:

CASE I - When a new motor is being purchased

CASE II - When considering rewinding a failed motor

CASE III - When an existing motor is operating inefficiently

The potential electricity saved is dependent on the horsepower (hp), speed, and percent load of the new and existing motors as defined in Equation 1.

$$E_s = 0.746 \frac{\text{kW}}{\text{HP}} \cdot \text{HP} \cdot (\eta_{\text{std}}^{-1} - \eta_{\text{high}}^{-1}) \quad (1)$$

where:

E_s = energy saved

HP = horse power

η_{std} = efficiency of standard motor

η_{high} = efficiency of standard motor

The potential dollars saved can be calculated by multiplying the energy saved in kW by the cost per kWh by hours of operation per year.

$$D_s = (E_s) (C_E) (H_{\phi}) \quad (2)$$

where:

D_s = dollars saved

E_s = energy saved

C_E = cost of electricity in \$/kWh

H_{ϕ} = hours of motor operation per year

For CASE I the simple payback can be calculated by subtracting the cost of the existing standard motor from the cost of the efficient motor and dividing the difference by the dollars saved per year. For CASE II the simple payback can be calculated by subtracting the cost of rewinding the existing standard motor from the cost of the efficient motor including all associated costs and dividing the difference by the dollars saved per year, calculated from Equation (2). For CASE III the simple payback can be calculated by subtracting the cost of operating the existing standard motor inefficiently from the cost of the efficient motor including all associated costs and dividing the difference by the dollars saved per year. Equation (3) summarizes the payback calculation.

$$P = \frac{C_{\text{high}} - C_{\text{std}}}{D_s} \quad (3)$$

where:

- P = simple payback in years
- C_{high} = efficient motor costs
- C_{std} = standard motor costs
- D_s = dollars saved per year

An efficient motor typically has a higher starting current than a standard motor and the potential effects on the motor power circuits should be analyzed. An efficient motor typically operates at a faster speed than a standard motor. Particular consideration should be given to the actual operating rpm specified. In some cases although the efficient motor is operating more efficiently the faster speed requires more energy to operate and could result in a net increase in energy expense, eliminating the cost effectiveness. For CASE I applications, speed sensitive loads should be considered carefully.

For CASE II applications, special high efficiency rewinding can yield a higher than manufactured efficiency for a standard motor, but will still be less than the NEMA 12-6C efficiency.

For CASE III applications, motor system consultants usually only consider motors with operating hours in excess of 2,000 hours per year. Applications such as emergency fire water pumps and back-up motors are only operated a few hours a year.

To further define CASE III, Tables 1 and 2 show the minimum operating hours required to yield simple paybacks between 2 and 10 years. Values are calculated at electrical rates between \$0.03/kWh and \$0.10/kWh. Table 1 is for Open Drip Proof (ODP) enclosure motors and Table 2 is for Totally Enclosed Fan Cooled (TEFC) and Explosion Proof enclosure motors. The tables are provided so that the user can quickly identify potential motor projects and eliminate from consideration most of the motors with a long or no payback. The assumptions include:

- The motors are at 75% of rated load since motor efficiency is usually the highest at 75% of rated output.

- The efficient motor is at nominal efficiency defined by NEMA 12-6C.

- The standard motor is at the average of the nominal efficiencies of currently manufactured motors that do not meet NEMA 12-6C.

- The user would choose an ODP, TEFC, or explosion proof enclosure.

- The demand charge and the incremental speed increase can be ignored.

To use the payback tables, locate the horsepower rating and speed rating in the appropriate columns. Identify the columns that are within your approximate energy charge in \$/kWh. The columns labeled with 2, 3, 4, or 5 indicate the simple payback years. The minimum annual hours of operation are included within the matrix. In the tables, spaces marked with a dashed line (---) indicate that even constant operation, 8,760 hours per year, would not yield a payback in the number of years listed. For example replacing an existing standard motor with an efficient motor that is rated a 40 hp and 1,800 rpm operating in a facility with an approximate energy charge of \$0.08/kWh would require at least 3,598 operating hours per year to yield a simple payback of 4 years.

Both tables show an increase in efficiency of approximately 5%. All tables in this article were generated using the Washington State Energy Office's Motor Master software. In general, incentives offered by motor distributors and/or electric utilities will yield a shorter payback. For example, a 10% discount on motor price can reduce the simple payback period by 0.2 to 0.3 years. Some typical rebates available from utilities around the country are:

Horsepower at 1,800 rpm	Rebate (\$)
10	140
20	260
40	430
50	500
75	730
100	920
200	1,300

Table 1. Hours of operation at various electrical rates and paybacks for open drip proof enclosure motors.

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Table 1 (Cont). Hours of operation at various electrical rates and paybacks for open drip proof enclosure motors.

Horse Power		RPM	At \$0.07/kWh										At \$0.08/kWh									
			Payback in Years										Payback in Years									
			2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
20	900					7897	6769	5923	5264	4738					8288	6907	5920	5180	4604	4144		
	1800		7030	5273	4218	3515	3013	2636	2343	2109			6137	4603	3682	3068	2630	2301	2046	1841		
	3600		6277	4708	3766	3138	2690	2354	2092	1883	8235	5490	4118	3294	2745	2353	2059	1830	1647			
40	900					8268	6890	5906	5168	4593	4134				7228	6023	5163	4518	4016	3614		
	1800	8235	5490	4118	3294	2745	2353	2059	1830	1647	7195	4797	3598	2878	2398	2056	1799	1599	1439			
	3600	8540	5693	4270	3416	2847	2440	2135	1898	1708	7475	4983	3738	2990	2492	2136	1869	1661	1489			
50	900					8102	6944	6076	5401	4861					8498	7082	6070	5311	4721	4249		
	1800	8535	5690	4268	3414	2845	2439	2134	1897	1707	7485	4977	3733	2988	2488	2133	1866	1659	1493			
	3600	8095	5397	4048	3238	2698	2313	2024	1799	1619	7100	4733	3550	2840	2367	2029	1775	1578	1420			
75	900					7352	6301	5514	4901	4411					7708	6423	5506	4818	4282	3854		
	1800		6027	4520	3616	3013	2583	2260	2009	1808	7895	5263	3948	3158	2632	2256	1974	1754	1579			
	3600		5857	4393	3514	2928	2510	2196	1952	1757	7875	5117	3838	3070	2558	2193	1919	1708	1535			
100	900					8540	7117	6100	5338	4744	4270				7480	6233	5343	4675	4156	3740		
	1800	8620	5747	4310	3448	2873	2463	2155	1916	1724	7535	5023	3768	3014	2512	2153	1884	1674	1507			
	3600		6453	4840	3872	3227	2766	2420	2151	1936	8480	5653	4240	3392	2827	2423	2120	1884	1696			
200	900					7610	6342	5436	4756	4228	3805				8318	6654	5545	4753	4159	3697		
	1800		6797	5098	4078	3398	2913	2549	2288	2039				5957	4488	3574	2978	2553	2234			
	3600		7853	5890	4712	3927	3366	2945	2618	2356				6867	5150	4120	3433	2943	2575			
300	1800		8530	6398	5118	4265	3656	3199	2843	2559				7487	5600	4480	3733	3200	2800			
	3600		6650	4888	3990	3325	2850	2494	2217	1995				5817	4363	3490	2908	2493	2181			
	400	900		8140	6105	4884	4070	3489	3053	2713	2442				7123	5343	4274	3562	3053			
400	1800			7425	5940	4950	4243	3713	3300	2970				8647	6485	5188	4323	3706	3243			
	3600		6923	5193	4154	3462	2967	2596	2308	2077				6057	4543	3634	3028	2596	2271			
Horse Power		RPM	At \$0.09/kWh										At \$0.10/kWh									
			Payback in Years										Payback in Years									
			2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
20	900					7368	6140	5263	4605	4093	3684				8288	6630	5525	4736	4144	3683		
	1800	8180	5453	4090	3272	2727	2337	2045	1818	1636	7380	4920	3690	2952	2460	2109	1845	1640	1476			
	3600	7335	4890	3668	2934	2445	2096	1834	1630	1467	6600	4400	3300	2640	2200	1886	1650	1467	1320			
40	900					8038	6430	5358	4593	4019	3572	3215			7240	5792	4827	4137	3620			
	1800	6400	4267	3200	2560	2133	1829	1600	1422	1280	5770	3847	2885	2308	1923	1649	1443	1282				
	3600	6635	4423	3318	2654	2212	1896	1659	1474	1327	5980	3987	2990	2392	1993	1709	1495	1329				
50	900					7560	6300	5400	4725	4200	3780				8500	6800	5667	4857	4250			
	1800	6635	4423	3318	2654	2212	1896	1659	1474	1327	5960	3973	2980	2384	1987	1703	1490	1324				
	3600	6300	4200	3150	2520	2100	1800	1575	1400	1260	5660	3773	2830	2264	1887	1617	1415	1258				
75	900					8580	6864	5720	4903	4290	3813	3432			7710	6188	5140	4406	3855			
	1800	7020	4680	3510	2808	2340	2006	1755	1560	1404	6320	4213	3160	2528	2107	1806	1580	1404				
	3600	6835	4557	3418	2734	2278	1953	1709	1519	1367	6150	4100	3075	2460	2050	1757	1538	1367				
100	900					8300	6840	5533	4743	4150	3689	3320			7480	5984	4987	4274	3740			
	1800	6695	4463	3348	2678	2232	1913	1674	1488	1339	6030	4020	3015	2412	2010	1723	1508	1340				
	3600	7535	5023	3768	3014	2512	2153	1884	1674	1507	6780	4520	3390	2712	2260	1937	1695	1507				
200	900					7400	5920	4933	4229	3700	3289	2960			6660	5328	4440	3806	3330			
	1800	7940	5293	3970	3176	2647	2269	1985	1764	1588	7140	4760	3570	2856	2380	2040	1785	1587				
	3600		6103	4578	3662	3052	2616	2289	2034	1831	8240	5493	4120	3296	2747	2354	2060	1831				
300	1800		6633	4975	3980	3317	2843	2488	2211	1990				5977	4483	3586	2988	2561				
	3600	7745	5163	3873	3098	2582	2213	1936	1721	1549	6975	4650	3488	2790	2325	1993	1744	1550				
	400	900		6330	4748	3798	3165	2713	2374	2110	1899	8550	5700	4275	3420	2850	2443	2138				
400	1800		7700	5775	4620	3850	3300	2888	2567	2310				6927	5195	4156	3463	2969				
	3600	8070	5380	4035	3228	2690	2306	2018	1793	1614	7275	4850	3638	2910	2425	2079	1819	1617				

Table 2. Hours of operation at various electrical rates and paybacks for totally enclosed, fan cooled, and explosion proof enclosure motors.

Horse Power RPM		At \$0.03/kWh Payback in Years										At \$0.04/kWh Payback in Years									
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
10	1800								7960	7076	6368					7957	6820	5968	5304	4774	
	3600							7571	6625	5889	5300				7936	6613	5689	4960	4409	3968	
20	1800							8721	7631	6783	6105					7637	6546	5728	5091	4582	
	3600						7972	6833	5979	5314	4783				7166	5972	5119	4479	3981	3583	
40	1800							8571	7500	6687	6000					7503	6431	5628	5002	4502	
	3600						7403	6346	5553	4936	4442			8323	6658	5548	4756	4161	3699	3329	
50	1800							8660	7578	6736	6062					7578	6496	5684	5052	4547	
	3600				8672	7227	6194	5420	4818	4336				8148	6518	5432	4656	4074	3621	3259	
75	900																				
	1800									7894	7105						7609	6658	5918	5326	
100	3600								7840	6989	6272					7840	6720	5880	5227	4704	
	1800							8333	7407	6666					8322	7133	6241	5548	4993		
200	3600								8439	7585							8147	7129	6337	5703	
	900																		7903	7113	
300	1800																		8196	7376	
	3600								8692	7823							8386	7338	6522	5870	
400	900																				
	1800							8683	7718	6946						8887	7448	6515	5791	5212	
500	3600							8103	7202	6482						8103	6946	6078	5402	4862	
	900																		8594	7735	
600	1800							8410	7476	6728						8410	7209	6308	5607	5046	
	3600								8410	7569							8109	7095	6307	5676	

Horse Power RPM		At \$0.05/kWh Payback in Years										At \$0.06/kWh Payback in Years									
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
10	1800				7638	6365	5456	4774	4243	3819				7973	6378	5315	4556	3986	3543	3189	
	3600			7950	6360	5300	4543	3975	3533	3180				6615	5292	4410	3780	3308	2940	2646	
20	1800				7324	6103	5231	4578	4069	3662				7623	6098	5082	4356	3811	3388	3049	
	3600			7180	5728	4773	4091	3580	3182	2884			7970	5978	4782	3985	3416	2989	2657	2391	
40	1800		8670	6503	5202	4335	3716	3251	2890	2601				7490	5992	4993	4280	3745	3329	2996	
	3600		8143	6108	4886	4072	3490	3054	2714	2443			7417	5563	4450	3708	3179	2781	2472	2225	
50	1800				7272	6060	5194	4545	4040	3638				7578	6062	5052	4330	3789	3368	3031	
	3600			6658	5326	4438	3804	3329	2959	2683			7243	5433	4346	3622	3104	2716	2414	2173	
75	900									8261								8608	7651	6886	
	1800				8532	7110	6094	5333	4740	4266					7114	5928	5081	4446	3952	3557	
100	3600				7516	6263	5369	4698	4176	3758				7840	6272	5227	4480	3920	3484	3136	
	1800				7988	6657	5708	4993	4438	3984				8323	6658	5548	4756	4161	3699	3329	
200	3600					7592	6507	5694	5061	4555					7604	6337	5431	4753	4224	3802	
	900						8121	7108	6317	5685						8232	7056	6174	5488	4939	
300	1800						8421	7369	6550	5895						8190	7020	6143	5460	4914	
	3600						7827	6709	5870	5218	4696				7832	6527	5594	4895	4351	3916	
400	900								8361	7525								7840	6969	6272	
	1800				8338	6948	5956	5211	4632	4169				8695	6956	5797	4969	4348	3864	3478	
500	3600				7778	6482	5556	4861	4321	3889				8103	6482	5402	4630	4051	3601	3241	
	900						8264	7231	6428	5785						8585	7359	6439	5723	5151	
600	1800				8078	6732	5770	5049	4488	4039				8410	6728	5607	4806	4205	3738	3364	
	3600					7562	6481	5671	5041	4537					7568	6307	5406	4730	4204	3784	

Table 2 (Cont). Hours of operation at various electrical rates and paybacks for totally enclosed, fan cooled, and explosion proof enclosure motors.

Horse Power		At \$0.07/kWh Payback in Years										At \$0.08/kWh Payback in Years									
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
10	1800	—	—	6833	5466	4555	3904	3416	3037	2733	—	—	7970	5978	4782	3985	3416	2989	2657	2391	
	3600	—	—	7563	5673	4538	3782	3241	2836	2521	2289	—	—	6630	4973	3978	3315	2841	2486	2210	1989
20	1800	—	—	8730	6548	5238	4365	3741	3274	2910	2619	—	—	7620	5715	4572	3810	3266	2858	2540	2286
	3600	—	—	8833	5125	4100	3417	2929	2563	2278	2050	—	—	5987	4490	3592	2993	2566	2245	1896	1796
40	1800	—	—	8553	6415	5132	4277	3666	3208	2851	2566	—	—	7503	5628	4502	3772	3216	2814	2501	2251
	3600	—	—	6337	4753	3802	3168	2716	2378	2112	1901	8325	5550	4163	3330	2755	2379	2081	1850	1665	
50	1800	—	—	8670	6503	5202	4335	3716	3251	2890	2601	—	—	7593	5695	4556	3797	3254	2848	2531	2278
	3600	—	—	6190	4643	3714	3095	2653	2321	2063	1857	8150	5433	4075	3260	2717	2329	2038	1811	1630	
75	900	—	—	—	—	—	8436	7381	6561	5905	—	—	—	—	—	8600	7371	6450	5733	5160	
	1800	—	—	7623	6098	5082	4356	3811	3388	3049	—	—	—	—	8658	5326	4438	3804	3329	2959	2663
100	3600	—	—	6723	5378	4482	3841	3381	2988	2689	—	—	7827	5870	4696	3913	3354	2935	2609	2348	
	1800	—	—	7140	5712	4760	4080	3570	3173	2856	—	—	8320	6240	4992	4160	3566	3120	2773	2496	
200	3600	—	—	8148	6518	5432	4656	4074	3621	3259	—	—	7118	5694	4745	4067	3559	3163	2873	2847	
	900	—	—	—	—	8128	6773	5806	5080	4518	4084	—	—	—	—	7114	5928	5081	4446	3952	3557
300	1800	—	—	—	—	8428	7022	6019	5266	4681	4213	—	—	—	—	7378	6147	5289	4610	4098	3688
	3600	—	—	8388	6710	5592	4793	4194	3728	3355	—	—	7335	5888	4890	4191	3668	3260	2934		
400	900	—	—	—	—	—	7884	6724	5777	5379	—	—	—	—	—	7840	6720	5880	5227	4704	
	1800	—	—	7448	5958	4965	4256	3724	3310	2979	—	—	8700	6525	5220	4350	3729	3283	2900	2610	
500	3600	—	—	6943	5554	4628	3967	3471	3086	2777	—	—	8087	6065	4852	4043	3468	3033	2696	2426	
	900	—	—	—	—	8830	7358	6307	5519	4906	4415	—	—	—	—	7728	6438	5519	4829	4292	3863
600	1800	—	—	7205	5764	4803	4117	3603	3202	2882	—	—	8410	6308	5048	4295	3604	3154	2803	2523	
	3600	—	—	8103	6482	5402	4630	4051	3601	3241	—	—	7095	5678	4730	4054	3548	3153	2838		

Horse Power		At \$0.09/kWh Payback in Years										At \$0.10/kWh Payback in Years									
		2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10		
10	1800	—	—	7087	5300	4240	3533	3029	2650	2356	2120	—	—	6373	4780	3824	3187	2731	2390	2124	1912
	3600	—	—	5900	4425	3540	2950	2529	2213	1987	1770	7930	5287	3965	3172	2643	2266	1983	1762	1586	
20	1800	—	—	6777	5083	4068	3388	2904	2541	2259	2033	—	—	6103	4578	3682	3052	2616	2289	2034	1831
	3600	7975	5317	3988	3190	2658	2279	1994	1772	1595	7180	4787	3590	2872	2393	2051	1795	1596	1436		
40	1800	—	—	6657	4993	3994	3328	2853	2496	2219	1997	—	—	5987	4490	3592	2993	2566	2245	1996	1796
	3600	7405	4937	3703	2962	2468	2116	1851	1648	1481	6655	4437	3328	2662	2218	1901	1664	1479	1331		
50	1800	—	—	6747	5080	4048	3373	2891	2530	2249	2024	—	—	6073	4555	3644	3037	2603	2278	2024	1822
	3600	7230	4820	3615	2892	2410	2066	1808	1607	1446	6525	4350	3263	2610	2175	1864	1631	1450	1305		
75	900	—	—	—	—	—	7650	6557	5738	5100	4590	—	—	—	—	8268	6890	5906	5168	4593	4134
	1800	—	—	7883	5913	4730	3942	3379	2956	2628	2365	—	—	7097	5323	4258	3548	3041	2661	2366	2129
100	3600	—	—	6980	5235	4188	3490	2991	2618	2327	2094	—	—	6280	4710	3768	3140	2691	2355	2093	1884
	1800	—	—	7417	5563	4450	3708	3179	2781	2472	2225	—	—	6680	4995	3996	3330	2854	2498	2220	1998
200	3600	—	—	—	—	—	7368	6316	5528	4912	4421	—	—	7593	5695	4556	3797	3254	2848	2531	2278
	900	—	—	—	—	7908	6326	5272	4519	3954	3514	6183	—	—	7118	5694	4745	4067	3559	3163	2847
300	1800	—	—	—	—	8190	6552	5460	4680	4095	3640	3276	—	—	7380	5904	4920	4217	3690	3280	2952
	3600	—	—	8700	6525	5220	4350	3729	3263	2900	2610	—	—	7827	5870	4696	3913	3354	2935	2609	2348
400	900	—	—	—	—	8356	6863	5769	5223	4642	4178	—	—	—	—	7534	6278	5381	4709	4186	3767
	1800	—	—	7710	5783	4626	3855	3304	2891	2570	2313	—	—	6950	5213	4170	3475	2979	2606	2317	2085
500	3600	—	—	7213	5410	4328	3607	3091	2705	2404	2164	—	—	6483	4863	3890	3242	2779	2431	2161	1945
	900	—	—	—	—	8585	6868	5723	4906	4293	3816	3434	—	—	7733	6186	5155	4419	3866	3437	3093
600	1800	—	—	7477	5608	4486	3738	3204	2804	2492	2243	—	—	6717	5038	4030	3358	2879	2519	2239	2015
	3600	—	—	8410	6308	5046	4205	3604	3154	2803	2523	—	—	7563	5673	4538	3782	3241	2836	2521	2269

DEPARTMENT OF THE NAVY

COMMANDING OFFICER
NFESC
560 CENTER DRIVE
PORT HUENEME CA 93043-4328

OFFICIAL BUSINESS

If you feel you have a feasible project after reviewing the data in Tables 1 and 2, please contact your EFD or NFESC. These agencies will assist you in validating your project and preparing the ECIP/ECAP documentation.

If you have any questions about efficient motors, please contact:

Gene Crank, Code ESC22, NFESC
(805) 982-5589 or DSN 551-5589